ASP, AEROSOL FORCING AND CLIMATE CHANGE

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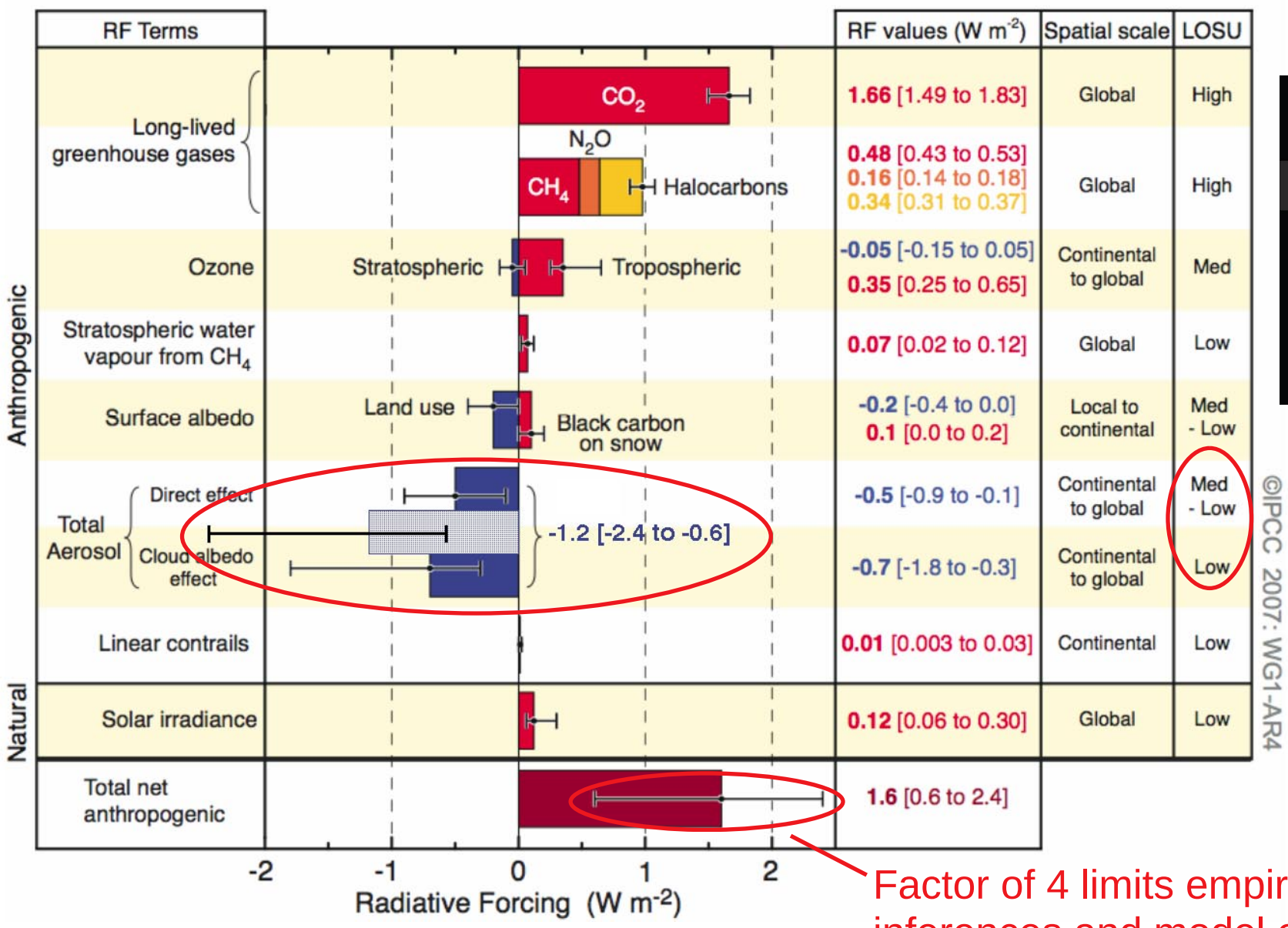
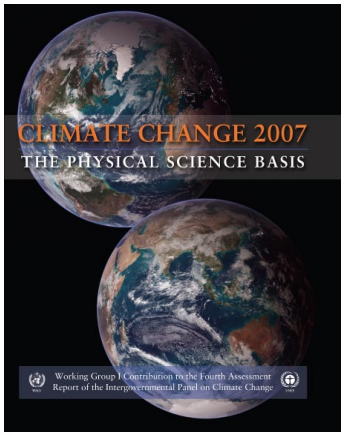
UNCERTAINTY IN AEROSOL FORCING AND ITS IMPLICATIONS

GLOBAL-MEAN RADIATIVE FORCINGS (RF)

Pre-industrial to present (Intergovernmental Panel on Climate Change, 2007)



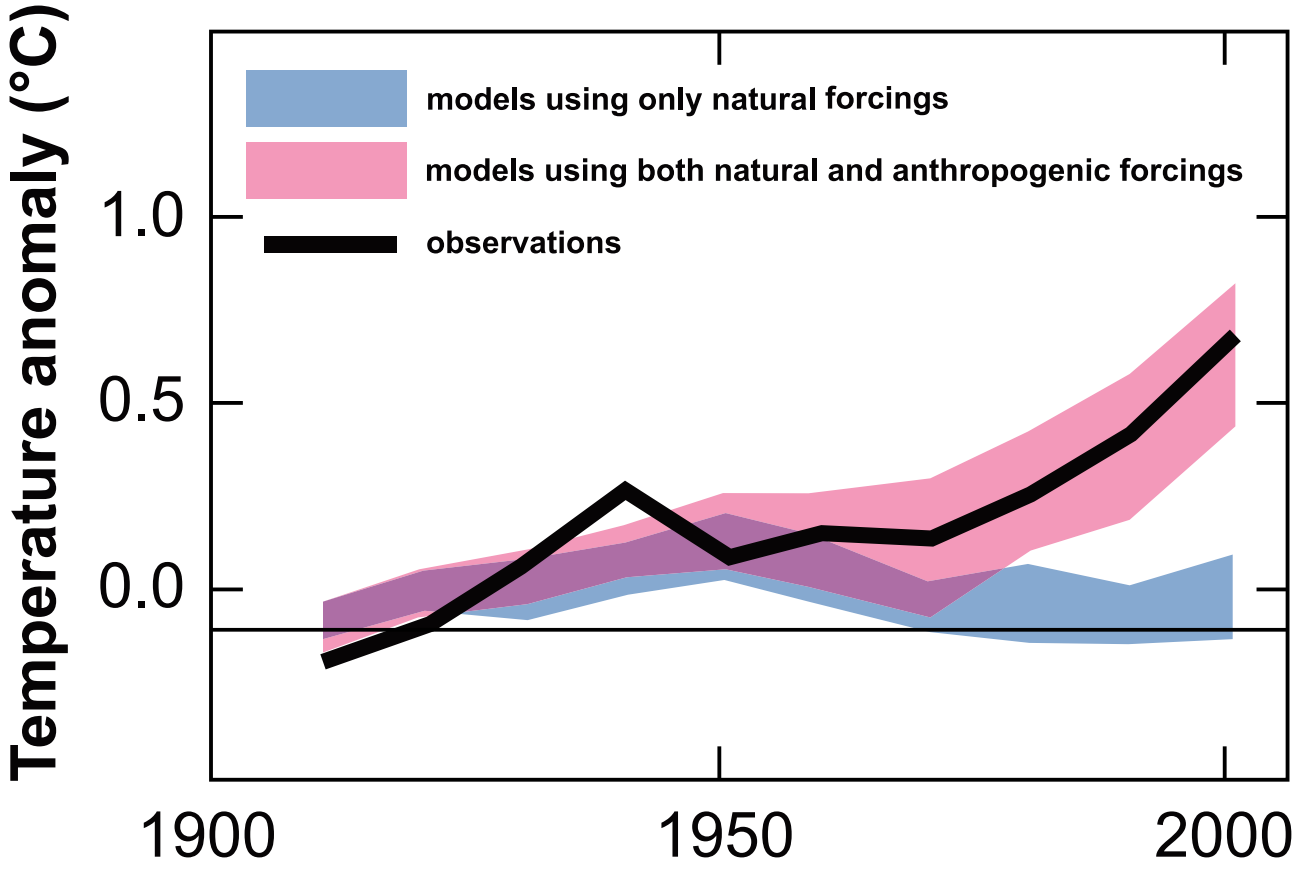


Factor of 4 limits empirical inferences and model evaluation.

LOSU denotes level of scientific understanding.

TOO ROSY A PICTURE?

Ensemble of 58 model runs with 14 global climate models

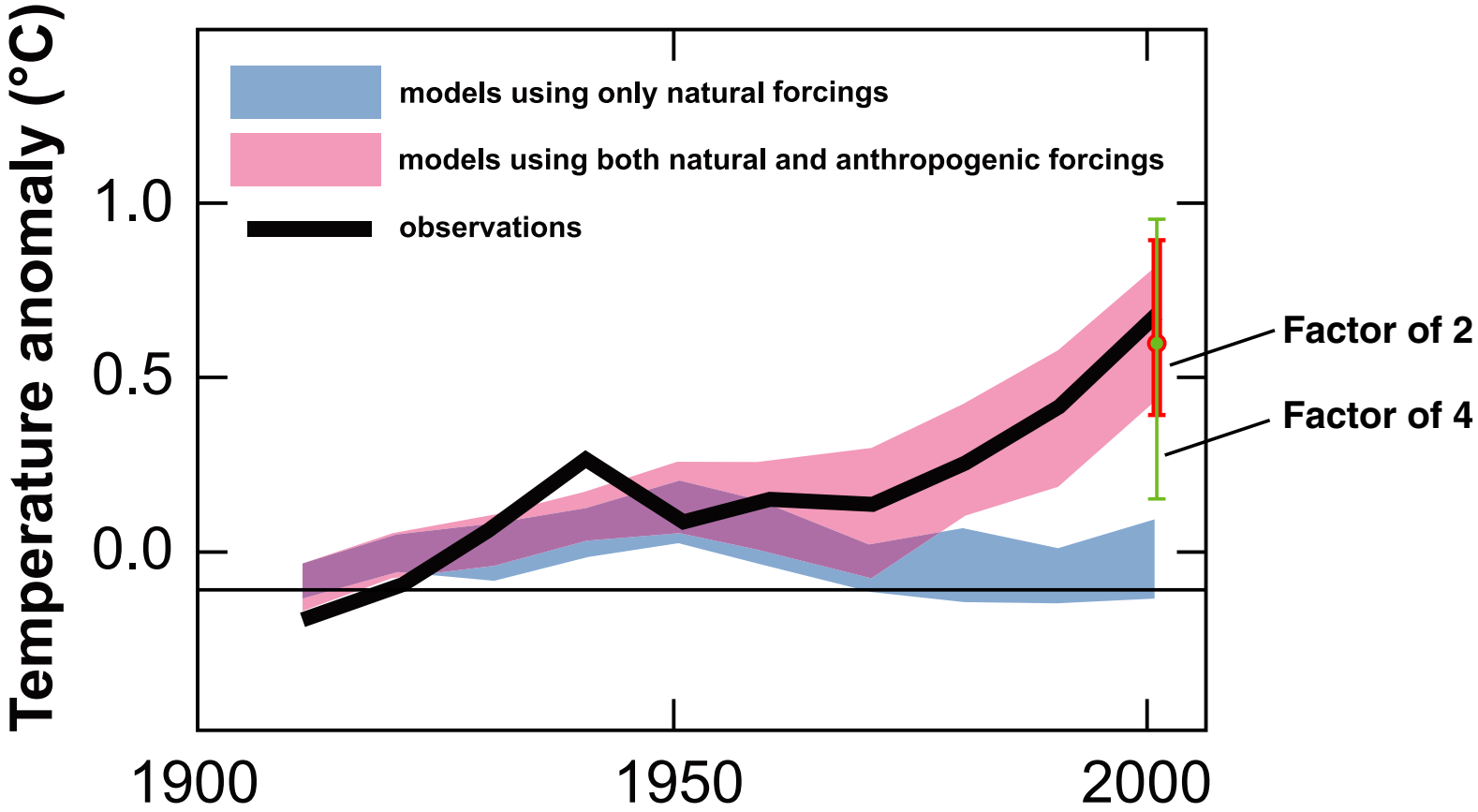


❝ Models can … simulate many observed aspects of climate change over the instrumental record. One example is that the ***global temperature trend over the past century … can be modelled with high skill when both human and natural factors that influence climate are included***.

IPCC AR4, 2007

TOO ROSY A PICTURE?

Ensemble of 58 model runs with 14 global climate models



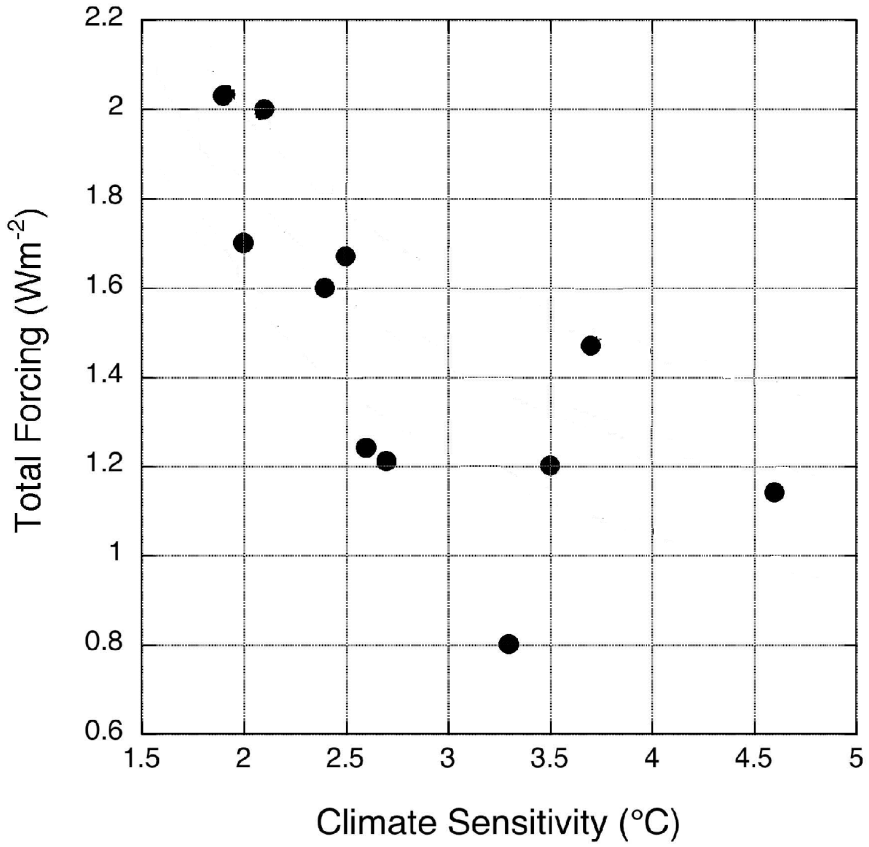
Schwartz, Charlson & Rodhe, Nature Reports – Climate Change, 2007

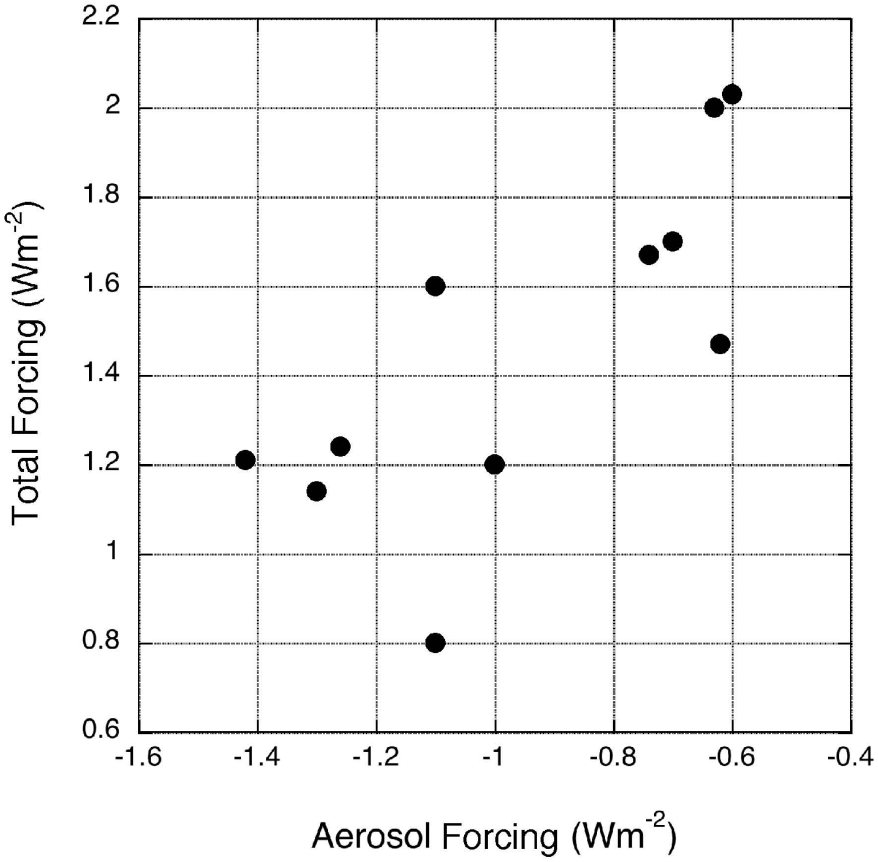
The models ***did not span the full range of the uncertainty*** and/or . . .

The forcings used in the model runs were ***anticorrelated with the sensitivities of the models***.

CORRELATION OF SENSITIVITY, TOTAL FORCING, AND AEROSOL FORCING IN CLIMATE MODELS

Eleven models used in 2007 IPCC analysis





J. Kiehl, GRL, 2007

Climate models with higher sensitivity have lower total forcing.

Total forcing increases with decreasing (negative) aerosol forcing.

These models cannot all be correct.

IMPLICATIONS OF UNCERTAINTY IN CLIMATE SENSITIVITY

Uncertainty in climate sensitivity translates directly into . . .

- Uncertainty in the amount of ***incremental atmospheric*** $\mathbf{CO_2}$ that would result in a given increase in global mean surface temperature.
- Uncertainty in the amount of ***fossil fuel carbon*** that can be combusted consonant with a given climate effect.

At present this uncertainty is more than a factor of 2.

Reduction in uncertainty in aerosol forcing is essential to reducing uncertainty in climate sensitivity.

DOE ROLE AND RESPONSIBILITY IN AEROSOL FORCING RESEARCH

2009 PRESIDENTIAL BUDGET

Office of Biological and Environmental Research

The Atmospheric Science Program (ASP) is focused on ***the radiative effects of atmospheric aerosols, the greatest source of uncertainty in global radiative forcing of climate change over the last century***.

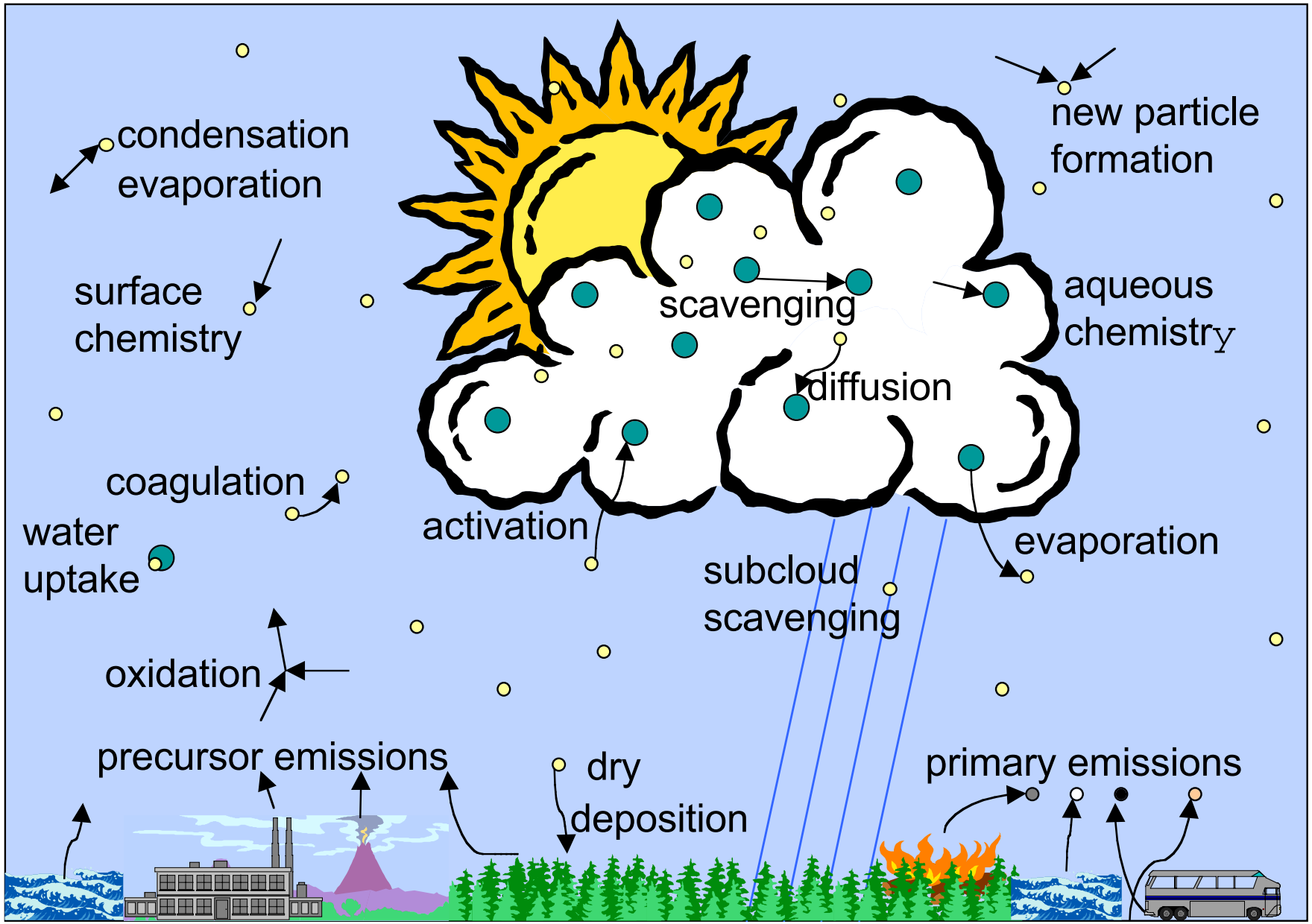
To enable more reliable and accurate simulations of direct and indirect aerosol climate forcing, the program conducts ***research on the atmospheric processes that control the formation, transport, transformations, and removal of atmospheric aerosols as these affect their distribution, radiative, and cloud nucleating properties***.

What's missing?

Determining aerosol radiative forcing

DETERMINING AEROSOL FORCING AND REPRESENTING IT IN CLIMATE MODELS

AEROSOL PROCESSES THAT MUST BE UNDERSTOOD AND REPRESENTED IN MODELS



Ghan and Schwartz, BAMS, 2007

REQUIREMENTS TO DETERMINE AEROSOL FORCING

Identification of the ***processes*** controlling aerosol forcing:

Emissions of primary aerosols and aerosol precursor gases.

Three dimensional transport.

Wet and dry deposition of particles and precursor gases.

Atmospheric aerosol ***formation and transformation*** (clear-air and in-cloud):

New particle formation, condensational growth, coagulation . . .

Affecting particle ***optical and cloud nucleating properties*** . . .

Affecting ***direct and indirect forcing***.

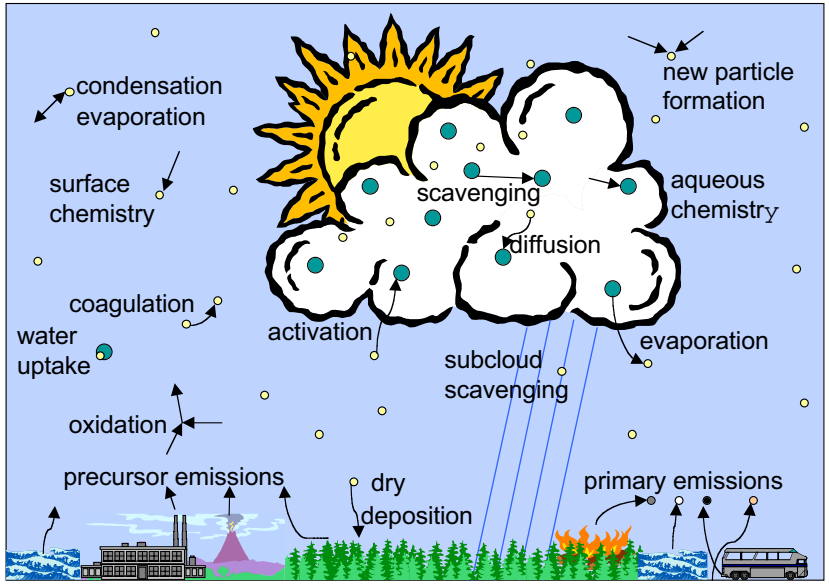
Developing ***quantitative understanding and numerical representations*** of these processes.

Evaluating these representations: ***compare models and observations***.

Applying these models at global scale to ***evaluate forcing*** at present, over secular time in the past, and for prospective future emission scenarios.

APPROACH TO DETERMINE AEROSOL FORCING

Numerical simulation of physical processes



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Isomorphism of processes to computer code

Modeling aerosol processes requires understanding these processes, developing and testing their numerical representations, and incorporating these representations in global scale models.

RESEARCH REQUIREMENTS

Emissions

Atmospheric processes

Global scale modeling

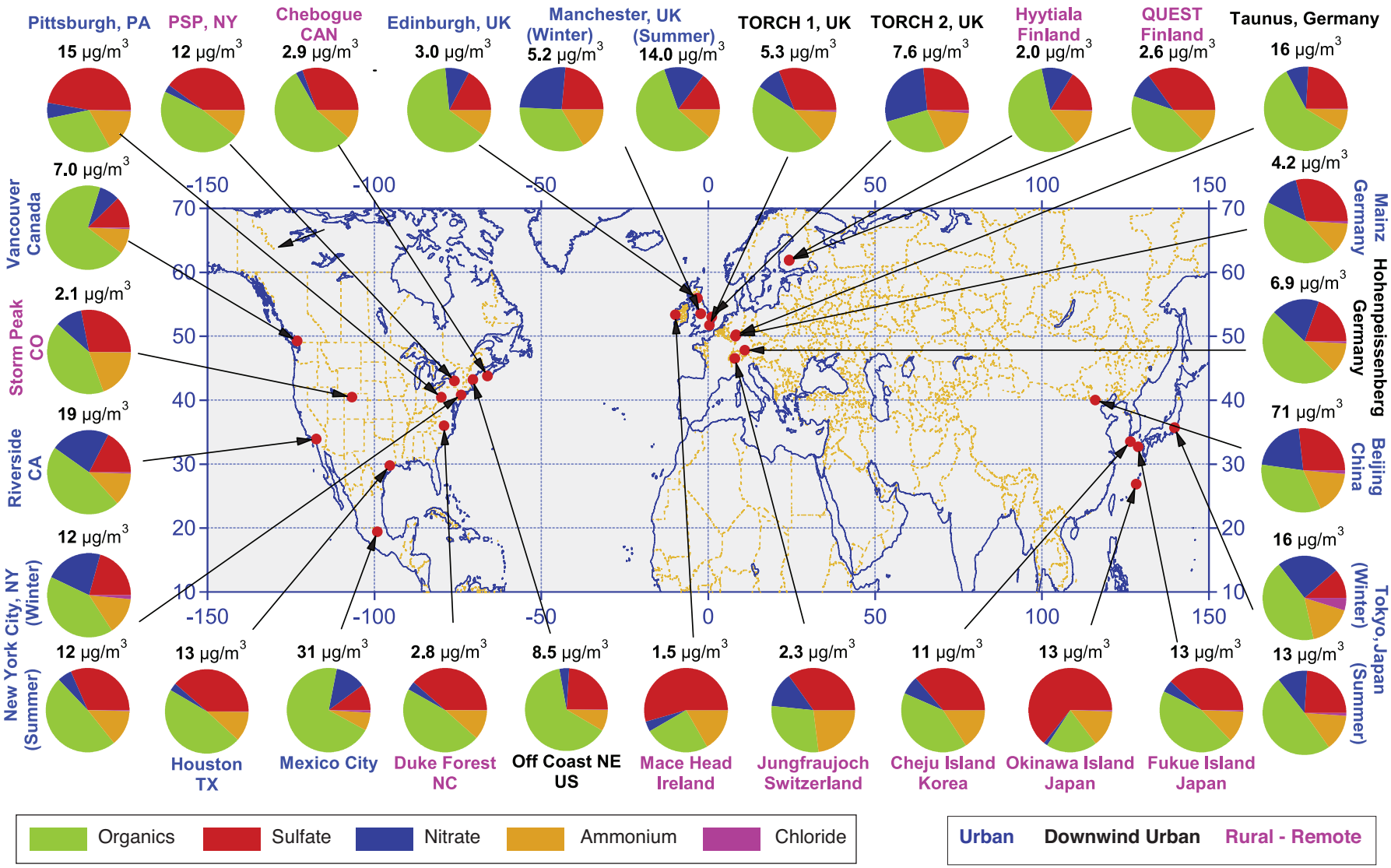
ATMOSPHERIC AEROSOL PROCESS RESEARCH

What's new?

Organics

DOMINANCE OF ORGANIC AEROSOL

Measurements by aerosol mass spectrometer

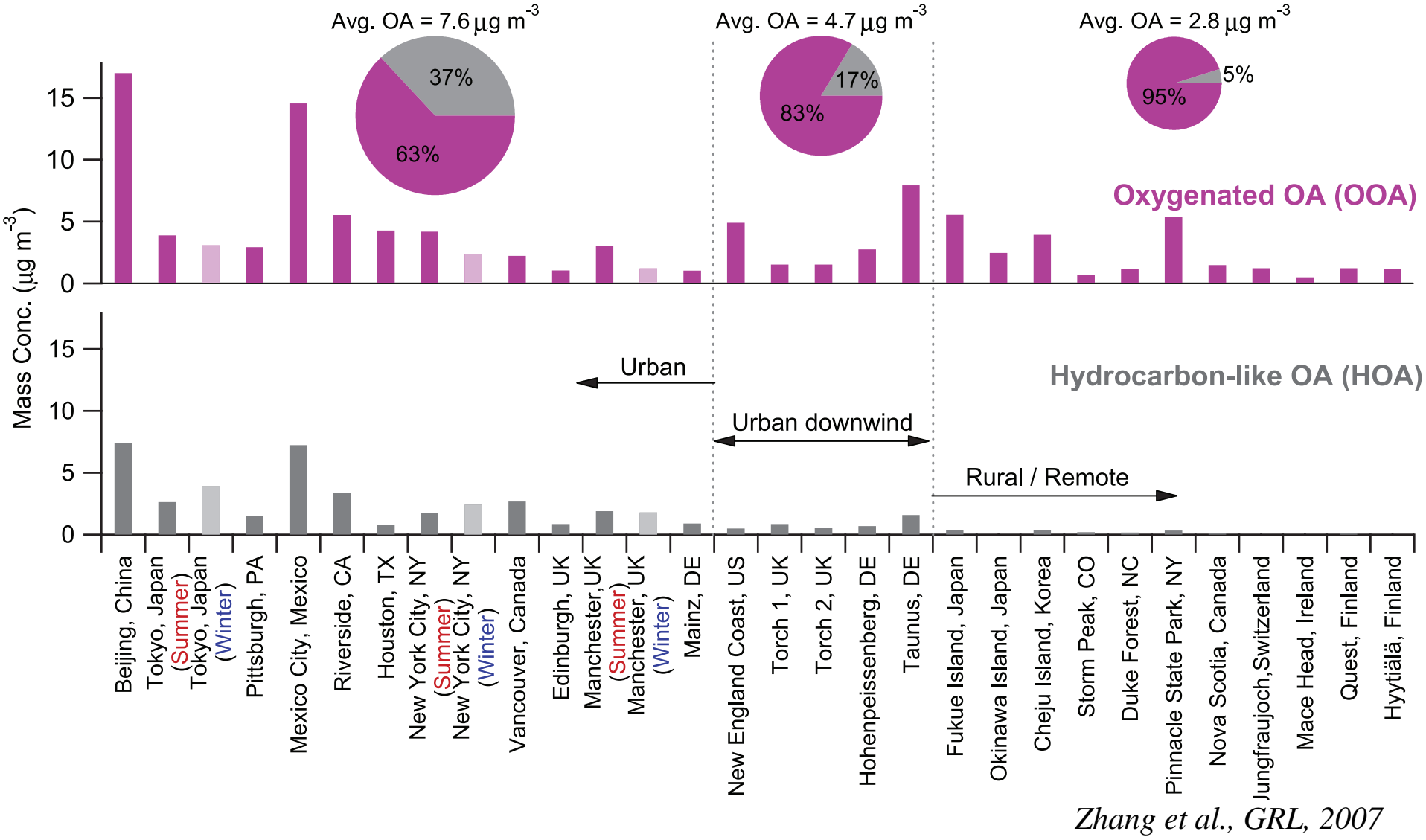


Zhang et al., GRL, 2007

Organic aerosol is major or dominant species throughout the anthropogenically influenced Northern Hemisphere.

HOA AND OOA BY LOCATION TYPE

Area of pie scaled to organic aerosol concentration

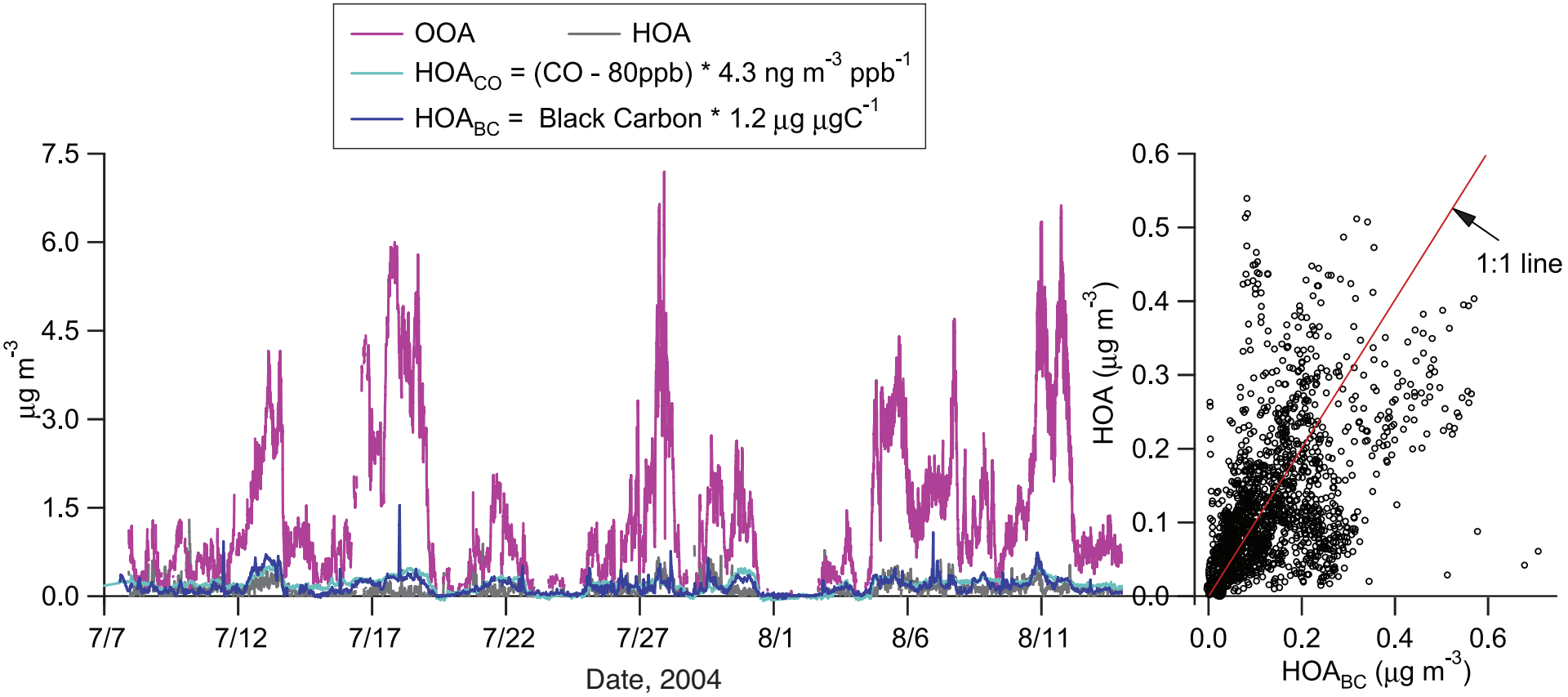


Zhang et al., GRL, 2007

OOA fraction increases with increasing distance from urban sources.

HOA AND OOA AT CHEBOGUE POINT, NS

Modeled HOA scaled to CO or black carbon



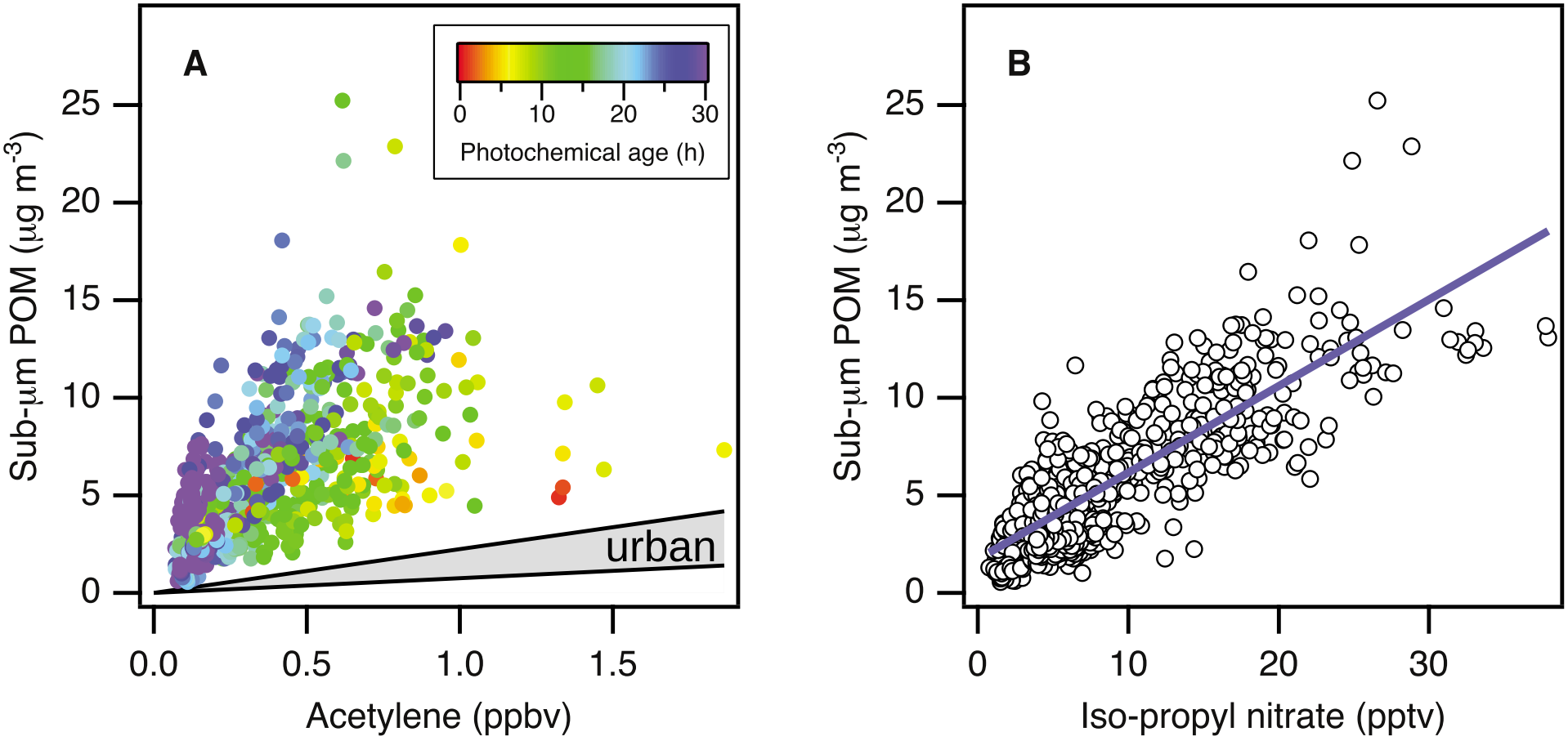
Zhang et al., GRL, 2007

Oxygenated organic aerosol (OOA) greatly exceeds hydrocarbon-like organic aerosol (HOA).

Measured HOA is closely matched by HOA scaled to CO or BC, indicative of primary emitted material.

ORGANIC AEROSOLS ARE SECONDARY

Correlation of organic aerosol with isopropyl nitrate vs. acetylene during New England Air Quality Study



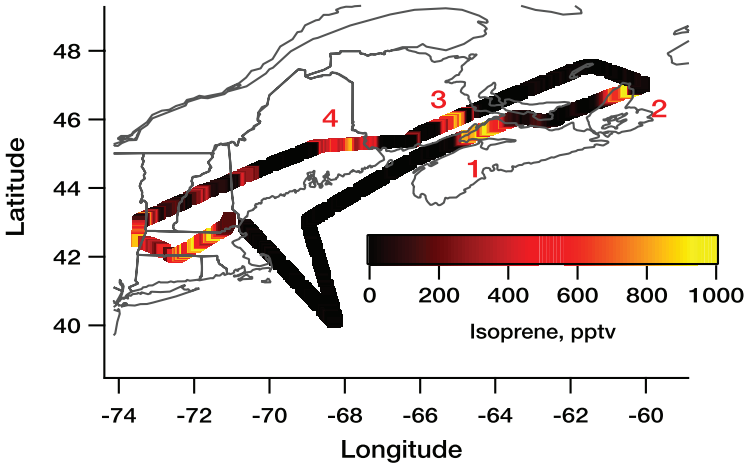
Modified from De Gouw et al., JGR, 2005

Acetylene is primary. Isopropyl nitrate is secondary.

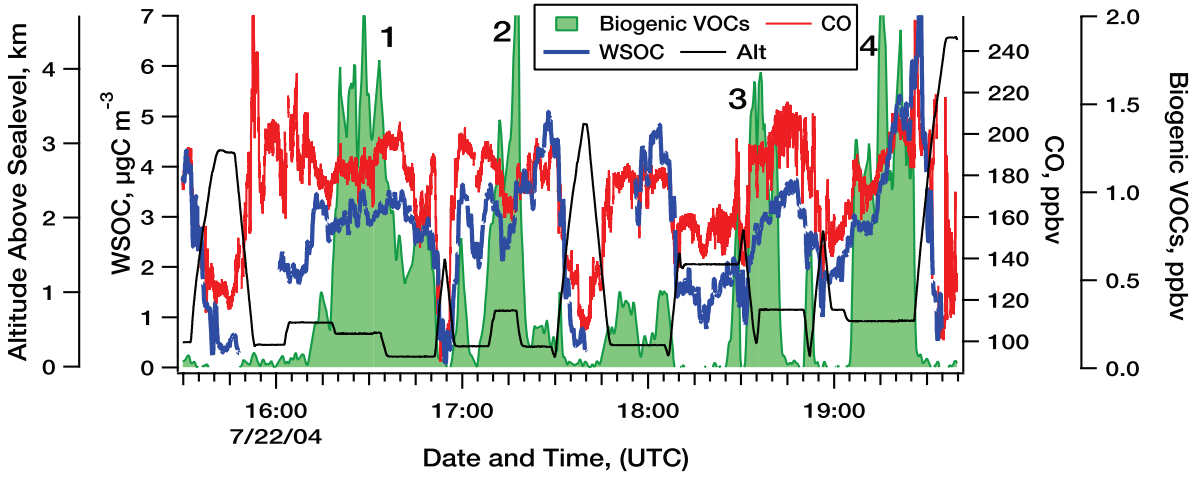
Photochemical age from toluene/benzene ratio.

BIOGENIC HCs + ANTHROPOGENIC EMISSIONS AS SOURCE OF ORGANIC AEROSOL

Water soluble organic aerosol, biogenic VOCs and CO during ICARTT



ICARTT
July 22, 2004



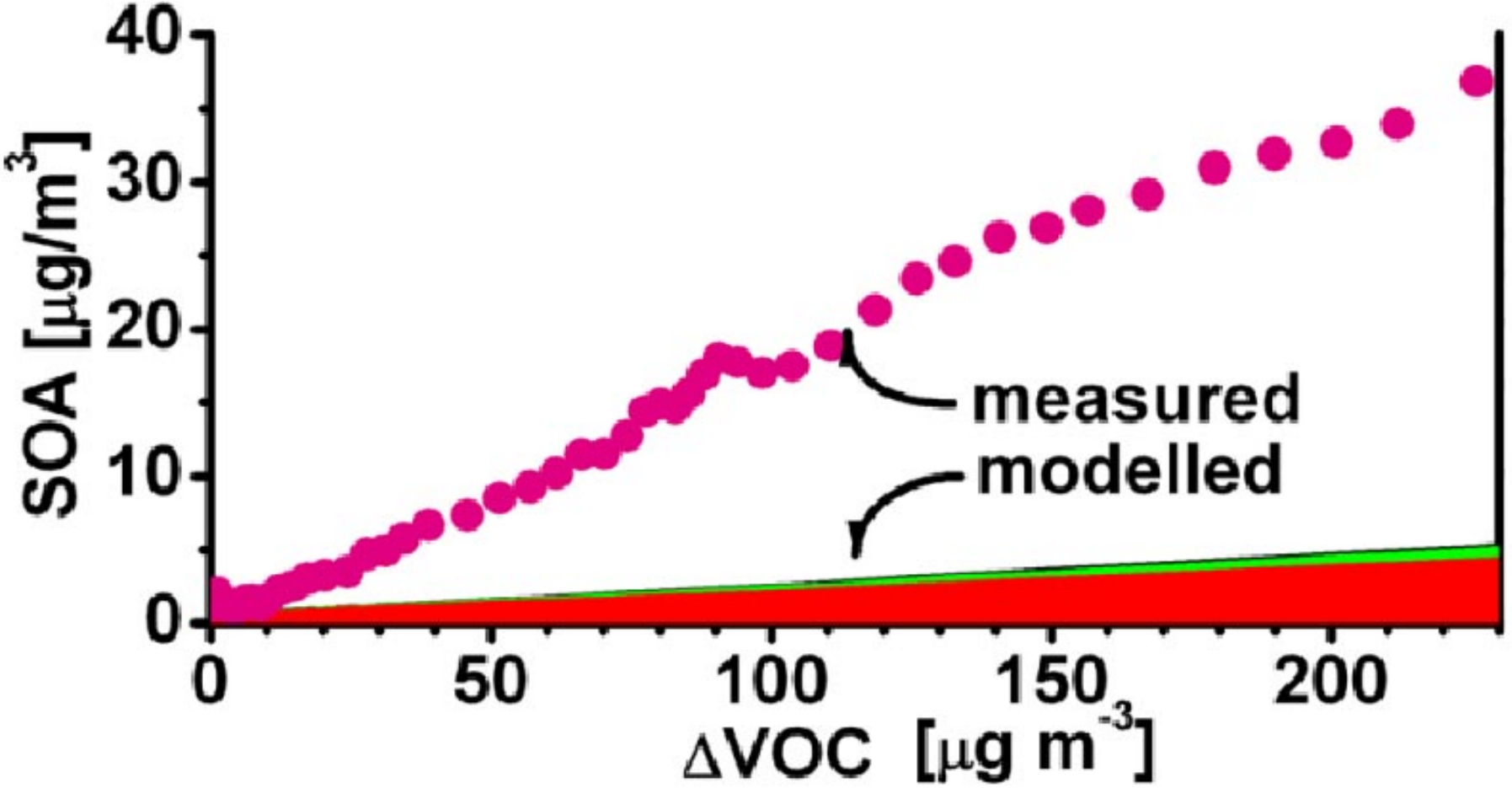
Weber et al., JGR, 2007

Carbon in WSOC is mainly modern carbon.

WSOC correlates with anthropogenic tracers CO and isopropyl nitrate.

MEASURED ORGANIC AEROSOL GREATLY EXCEEDS MODELED

Mexico City, April 9, 2003, prior to 2 p.m.



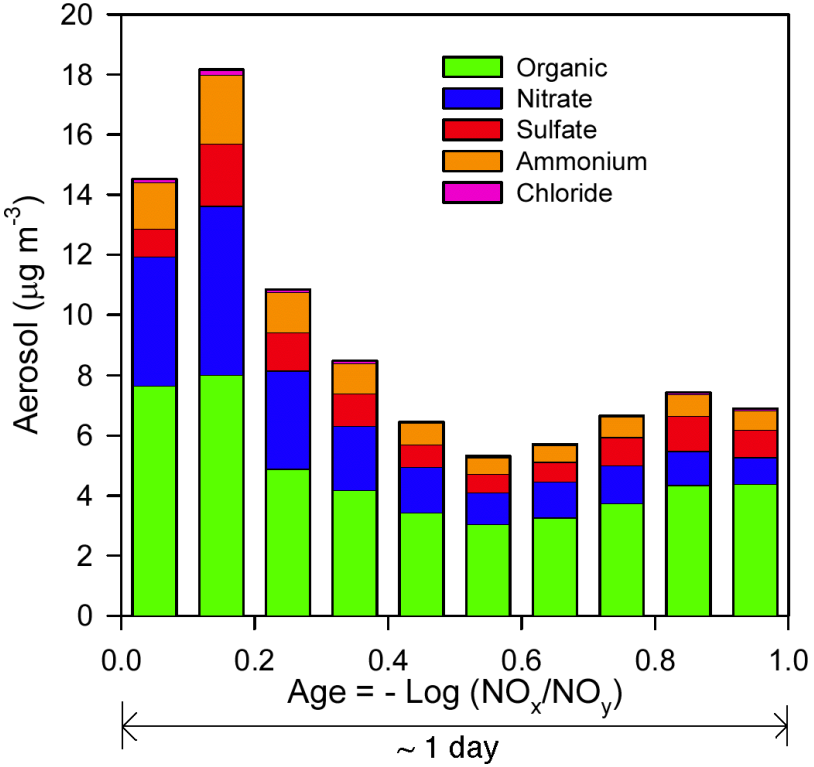
Modified from Volkamer et al., GRL, 2006

Comparison of measured oxygenated organic aerosol (OOA) and modeled secondary organic aerosol vs. decrease in volatile organic carbon.

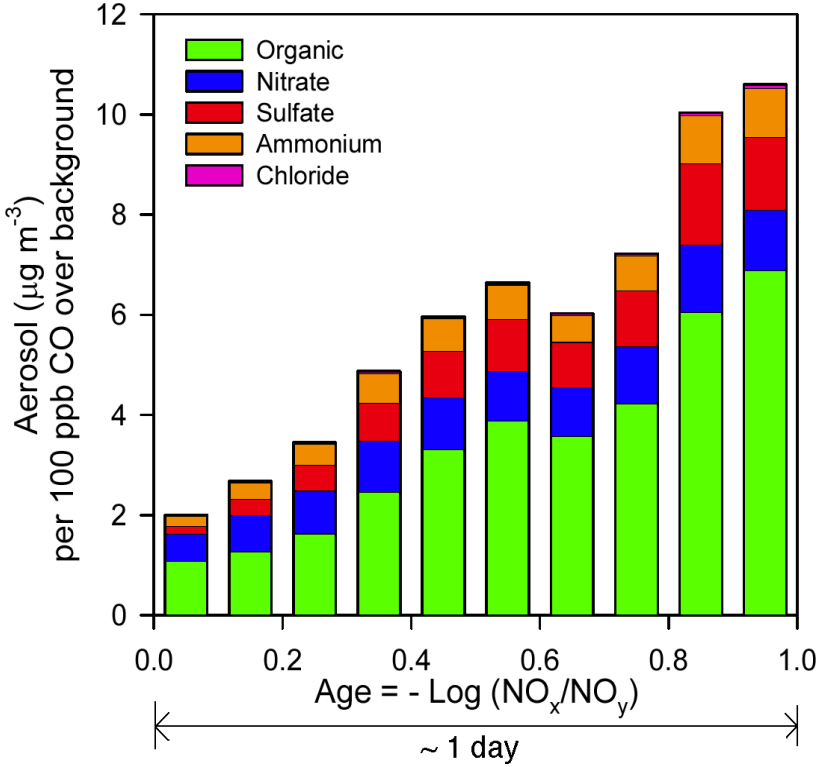
SECONDARY AEROSOL PRODUCTION

Parcel age measured using $-\text{Log}(NO_x/NO_y)$ as clock

Concentration



Normalized concentration



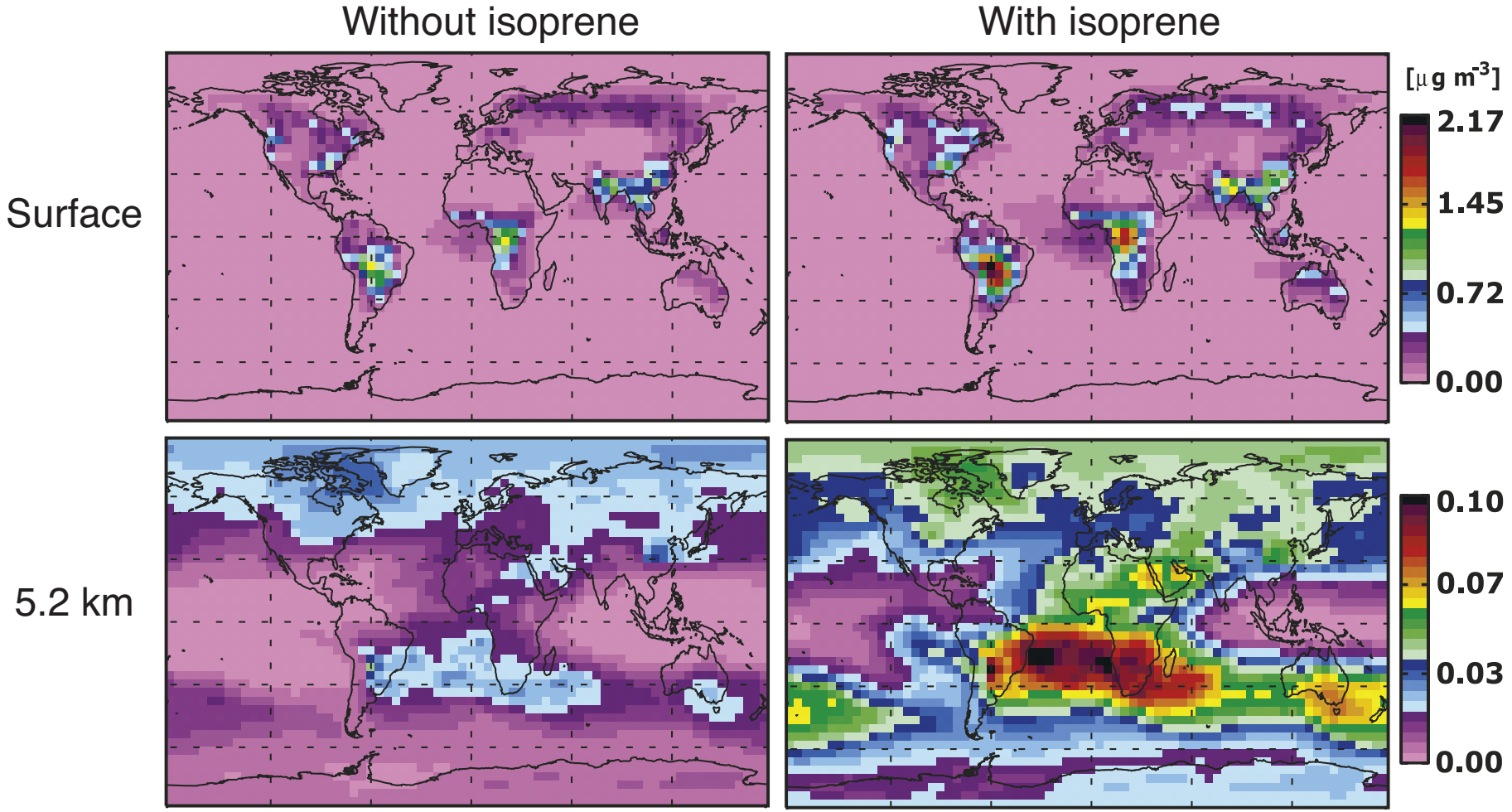
Dilution is accounted for by normalizing aerosol concentration to CO above background.

~5 × *increase* in total aerosol; **~7 × *increase*** in organic aerosol.

Measured increase in organic aerosol exceeds modeled based on laboratory experiments and measured volatile organic carbon ***tenfold***.

ISOPRENE ENHANCEMENT TO SECONDARY ORGANIC AEROSOL

Modeled SOA without and with isoprene at surface and 5.2 km



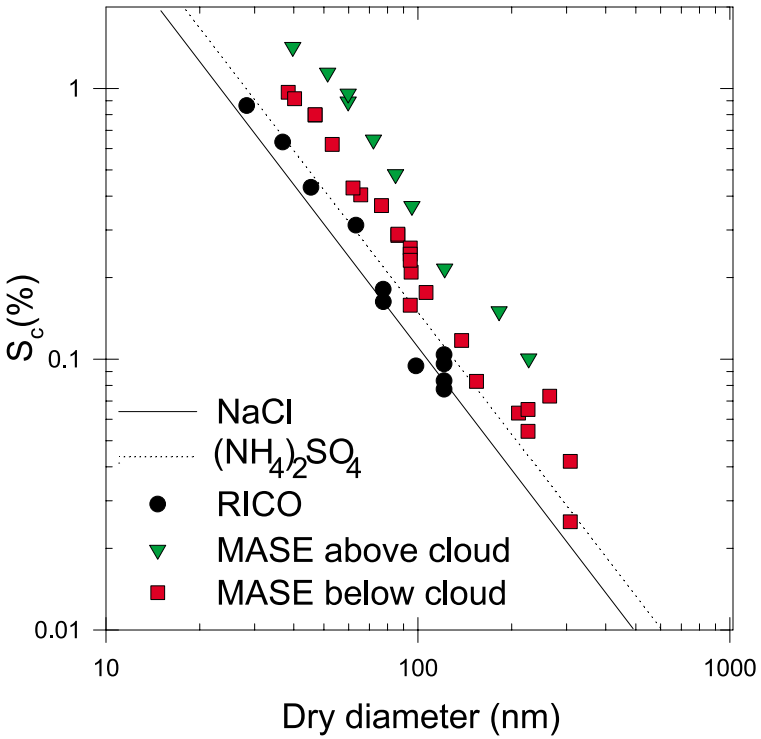
Henze and Seinfeld, GRL, 2006

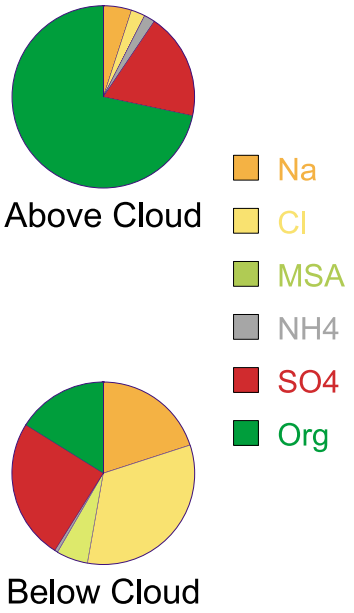
Isoprene increases global SOA by more than a factor of 2.

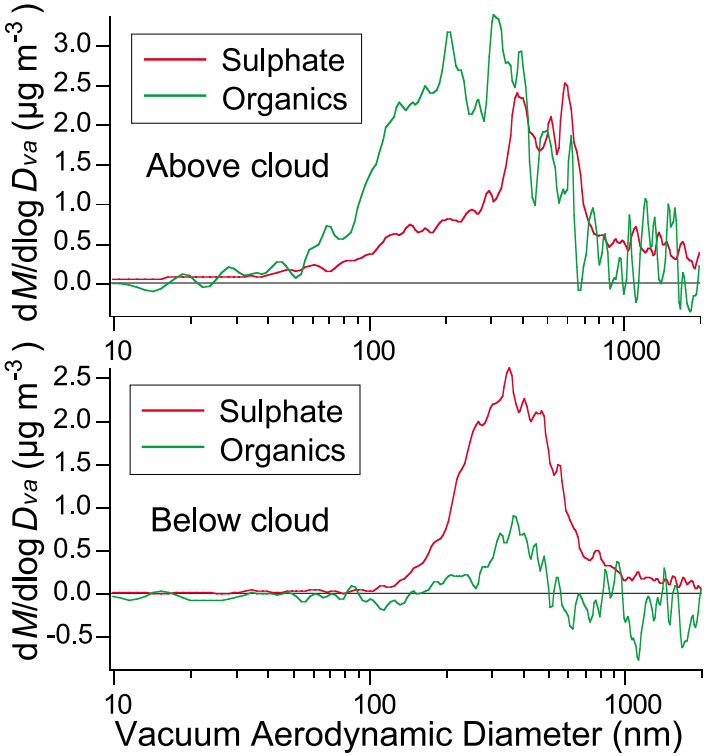
Relative enhancement is much greater in free troposphere (note different scales).

COMPOSITION MATTERS

Size dependent critical supersaturation of aerosol particles







J. Hudson, Y.-N. Lee, M. Alexander

Measurements below (110-170 m) and above (400-470 m) clouds off the coast of California, north of San Francisco, on July 25, 2005.

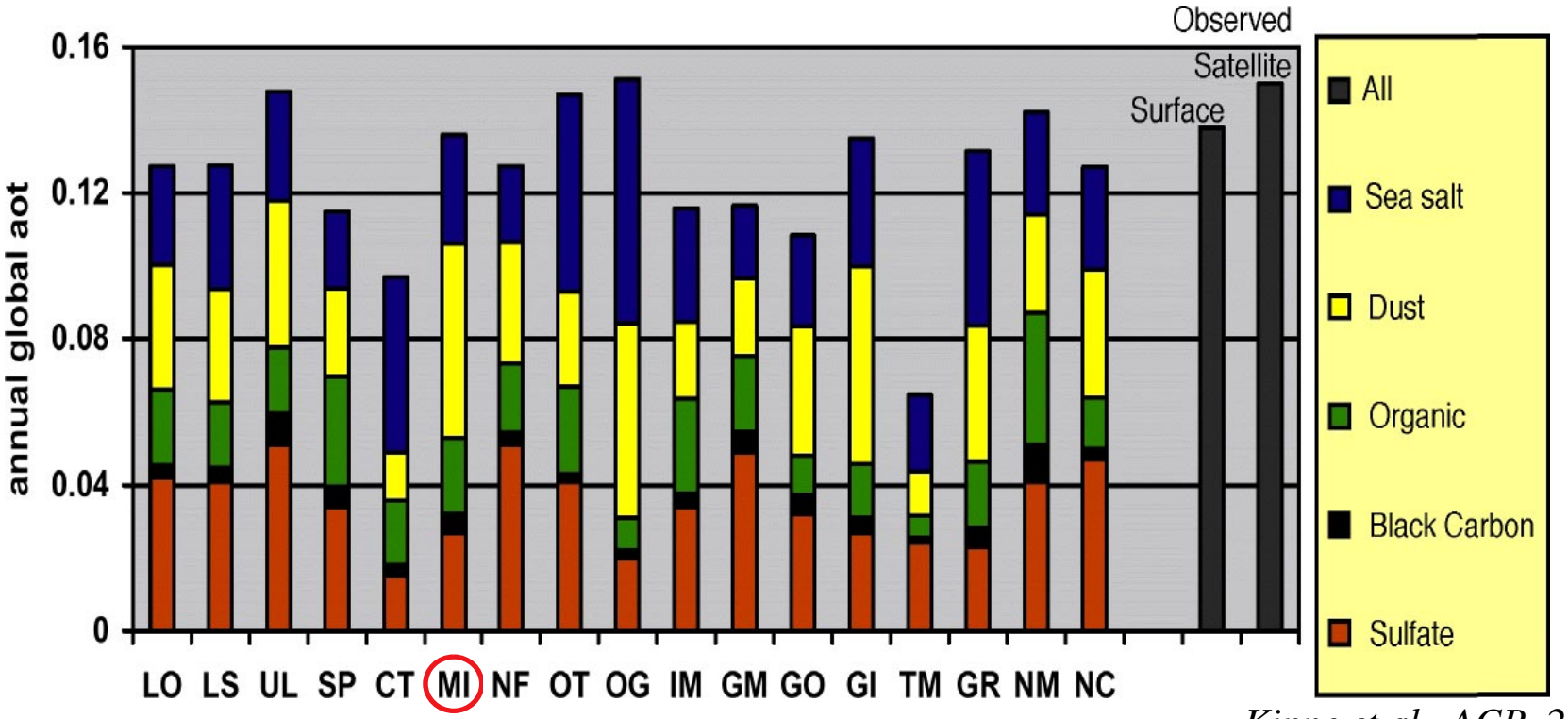
Higher supersaturation is required to activate particles with greater organic fraction.

Bulk composition determined by PILS (particle into liquid sampler).

Size-dependent composition determined by aerosol mass spectrometer.

AEROSOL OPTICAL DEPTH IN 17 MODELS (AEROCOM)

Comparison also with surface and satellite observations



Kinne et al., ACP, 2006

Surface measurements: AERONET network.

Satellite measurements: composite from multiple instruments/platforms.

Are the models getting the "right" answer for the wrong reason?

Are the models getting the "right" answer because the answer is known?

Are the satellites getting the "right" answer because the answer is known?

CONCLUSIONS

Aerosol forcing continues to be the greatest uncertainty in climate forcing over the industrial period.

The path to determine this forcing is clear but there are important missing components.

Understanding of the atmospheric processes is greatly improving but there is still much work to be done.

We have to beware of getting the right answer for the wrong reason.